

ON A PECULIAR FORM OF METAMORPHISM IN SILICEOUS SANDSTONE.

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It will be remembered that in 1891 attention was called to a crater-like depression in unaltered sedimentary rocks some twelve miles southeast of Canyon Diablo, Arizona, by the finding of a large number of masses of meteoric iron in the immediate vicinity. Subsequently the possible origin of the depression, or crater, was made a matter of investigation by Mr. G. K. Gilbert, of the U. S. Geological Survey, who gave his results in his presidential address before the Geological Society of Washington, in 1896, under the caption of *The Origin of Hypotheses*.

With the question of the origin of the crater the present paper has little to do. It is sufficient to say that Mr. Gilbert, after discussing various hypotheses, was led to regard that of an origin through explosive volcanic action as most plausible. This view has recently been discussed by Messrs. D. M. Barringer and B. C. Tilghman, of Philadelphia,^a who have undertaken a series of investigations based on the theory that the depression is due to the impact of a gigantic meteorite.

As is well known, the surface rock over a large part of the region is an arenaceous limestone, known as the Aubrey limestone, which has, according to Mr. Barringer, a thickness of some 350 feet. Immediately underlying this is a light gray sandstone from 450 to 500 feet in thickness. A peculiar and apparently very local form of metamorphism of this rock is the excuse for the present paper.

The sandstone (Cat. No. 76834 U.S.N.M.) in its original and prevailing type is of a light gray color, distinctly saccharoidal and, in the walls of the crater, very friable, being in small masses easily disintegrated in the hands. Under the microscope it is found to be composed

^aCoon Mountain and its Crater, *Proc. Acad. Nat. Sci. Phila.*, December, 1905. Issued March 1, 1906.

of well-rounded quartz granules with an occasional grain of a plagioclase feldspar, and a little dust-like material in the interstices, but the amount of interstitial material of any kind is very small. The general structure of the stone is shown in fig. 1 of Plate LII. This type passes into what may be called the first phase of the metamorphism—an almost chalky white rock—(Cat. No. 76835 U.S.N.M.), still retaining the granular character and much of the original structure of the sandstone, and crushing readily between the thumb and fingers. Under the microscope this type shows interesting structural changes which are only in part brought out by the photomicrograph reproduced in fig. 2 of Plate LII. A portion of the quartz granules retain their original characteristics. A larger portion are crushed and more or less distorted, though retaining their limpidity and high polarization colors. In many instances two adjacent granules are crushed and fractured at point of contact as though they had been struck a sharp blow with a hammer. This crushing has at times been carried so far that the rock is reduced to a fine sand (Cat. No. 76840 U.S.N.M.), each particle of which is as sharply angular as though disintegrated by a blast of dynamite (see fig. 4, Plate LII).^a Of greater significance from the present standpoint is the presence in the still firm rock of a large number of granules which are so completely changed as to give rise to forms at first glance scarcely recognizable as quartzes at all. A description of these is given in the discussion of the next phase of the metamorphism.

In this second and very complete phase of metamorphism the original granular structure of the sandstone has almost wholly disappeared, as have also the original lines of bedding (Cat. No. 76837, U.S.N.M.). The rock is chalk-white to cream-yellow in color, quite hard, though in thin fragments readily broken between the thumb and fingers, and lacks entirely the arenaceous structure. It resembles the decomposed chert quarried at Seneca, Missouri, under the name of tripoli, more than any other rock that the writer can call to mind, although on casual inspection it might readily pass for an old siliceous or calcareous sinter. This material, Mr. Tilghman writes, occurs sporadically throughout the pulverulent material, of which it constitutes some 2 per cent in bulk and in fragments from the fraction of an inch to 10 or 12 feet in diameter. In one instance the drill passed through a mass of it some 50 feet in thickness at a depth of 500 feet below the surface. In the mass this variety shows an uneven platy structure extending directly across the original, almost obliterated, lines of bedding. Under the microscope this phase exhibits certain features new to the writer, at least, and which are quite at variance with our ideas of the stable character of quartz sand. The general structure is shown in fig. 5 of Plate LII. A more highly magnified

^aThis is the material referred to as "Silica" by Messrs. Barringer and Tilghman, and of which there are said to be "millions of tons."

though less well-defined section is shown in fig. 3. At first glance such would be pronounced to be a holocrystalline rock. It is, in fact, an aggregate of closely interlocking quartz granules with low and very uniform relief, dull colors of polarization, and in the majority of instances a marked rhombohedral cleavage. So striking is this feature that at first the true nature of the mineral was not recognized. Extinctions are often undulatory, indicating a condition of molecular strain, and the cleavage lines are themselves at times more or less wavy. The appearance indeed is such as to suggest that the granules have been subjected to pressure while in a putty like or plastic condition. With a high power and between crossed Nicols (fig. 3 of Plate LII) the rock is seen to be not holocrystalline, but to contain comparatively small colorless interstitial areas, showing by ordinary light a fibrous structure, but which are for the most part completely isotropic between crossed Nicols, and which the chemical analysis suggests may be opal. From this condition the rock passes rarely through more or less vesicular to highly pumiceous forms (Cat. Nos. 76839 and 76840), showing to the unaided eye all the features of an obsidian pumice, but of a white color. This under the microscope is resolved into a colorless vesicular glass, more or less muddied through dust-like material and showing here and there residual particles of unaltered quartz. The glass does not, however, resemble the glass of a pumice, nor is it like that obtained by the artificial fusion of quartz in the geophysical laboratories of the Carnegie Institution. So far as the writer's observations go, it more closely resembles fulgurite glass, formed by the lightning striking in siliceous sand. This form, it is well to note, is quite rare, the material being first met with in what Mr. Barringer has designated as shaft No. 2, and at a depth of 130 feet. A few small pieces were found in digging the open cuts outside of the crater and but one piece lying out on the surface.

Chemical tests on (I) the unaltered sandstone; (II) what may be called the crystalline variety, the finely laminated stone compared to a decomposed chert, and (III) the pumice, gave Mr. Wirt Tassin results as below:

(I) Unaltered sandstone	{	SiO ₂	99.29
		Undet71
			<hr/> 100.00
(II) Altered sandstone	{	Si ₂ O	98.63
		Al ₂ O ₃	0.18
		Fe ₂ O ₃	0.10
		Ign	0.99
		Loss at 100°	0.30
			<hr/> 100.20

	{ SiO ₂ -----	95.22
	{ Al ₂ O ₃ -----	0.59
(III) Pumiceous variety -----	{ Fe ₂ O ₃ -----	0.19
	{ CaO -----	1.99
	{ Ign -----	1.20
	{ Loss at 100° -----	0.40
		<hr/> 99.59

A part of the lime in Analysis III was there as a mechanically admixed carbonate. The high ignition (0.99) in II would suggest that a part of the silica is in the condition of opal, as already noted. Eliminating the ignition and the free calcium carbonate in III, it is evident that there is no essential chemical difference in the three samples. They vary as little as would probably three independent analyses of any one of the types from slightly different sources.^a

As to the exciting cause of this metamorphism. So far as the writer has information, no more satisfactory theory has been advanced than that of the Messrs. Barringer and Tilghman,^b who ascribe it to the impact and incidental heat of an enormous mass of meteoric iron which constituted a portion of the well-known Canyon Diablo fall. Startling as it may seem, the writer, without intending to commit himself in any way, has to acknowledge that it must at least receive consideration, for the simple reason that nothing else seemingly worthy of consideration presents itself. That there must have been intense heat, and that, too, only for a brief period, is certainly manifest. The force of impact of an ordinary meteoric mass, as is well known, is not great and the depth of penetration but slight. The majority of those that come to our earth are, however, following it in its orbit about the sun, and their speed on entering our atmosphere is, so far as determined, only some 3 to 10 miles a second. If, however, we conceive a mass—as from the Leonides—meeting the earth head on, as it were, it would enter our atmosphere with an initial speed of 45 miles a second. If such a mass were of sufficient size to escape anything like complete destruction through burning, its force of impact would be enormous. Whether it could or did produce the effects described is, perhaps, yet an open question.

^aAt the time Mr. Gilbert was making his investigations a chemical analysis was made by W. H. Melville, of the vesicular variety (No. III). This Mr. Gilbert has placed in my hands. It is as follows: SiO₂—89.71; Al₂O₃—1.20; FeO—0.34; CaO—4.22; MgO—0.22; K₂O—0.15; Na₂O—0.24; Co₂—3.25; Ign.—0.74; loss at 100°—0.20. Total, 100.27.

^bCoon Mountain and its Crater. Proc. Acad. Nat. Sci., Phila. 1905, p. 885.